Reservoir computing of a three-dimensional turbulent atmospheric boundary layer

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Turbulent convection is a central process in Earth's climate system. As the corresponding length and time scales range over many orders of magnitude, general circulation models compute the large-scale flow only, while small-scale turbulence has to be parameterized. A common approach is the mass-flux scheme, where the vertical turbulent heat flux is approximated via an updraft/environment decomposition of the fluid layer. Such a scheme assumes a simplistic model of thermals rising from the ground towards the free atmosphere and is very sensitive to the chosen parameter values.

We propose an alternative approach with an echo state network (ESN) for time series forecast. The ESN is one implementation of a recurrent neural network, where only the output layers are trained by linear regression. This reservoir computing (RC) method serves as light weight substitute for a direct solution of the underlying fluid equations, as the training process is computationally inexpensive. RC has shown great promise in predicting two-dimensional convection flows with correct statistical properties[1]. Recently it has been demonstrated that it can also generalize between different boundary conditions and infer correct profiles of a two-dimensional dry atmospheric boundary layer model[2].

Here we train a convolutional autoencoder network on three-dimensional DNS data of a dry atmospheric boundary layer growing into a stably stratified free atmosphere. We analyze vertical and horizontal slices of the three-dimensonal flow and use the neural network to compress information on the strong vertical updrafts into a low-dimensional latent space. This low-order representation is then fed to an ESN in order to perform the task of predicting dynamics. The advanced latent space is then processed by the decoder of the network to yield a prediction to the narrow updrafts and thermals. We further analyze the predicted flow in terms of its statistical properties. Our results indicate that this approach can be used as low-cost parameterization scheme with high accuracy in large-scale circulation models.

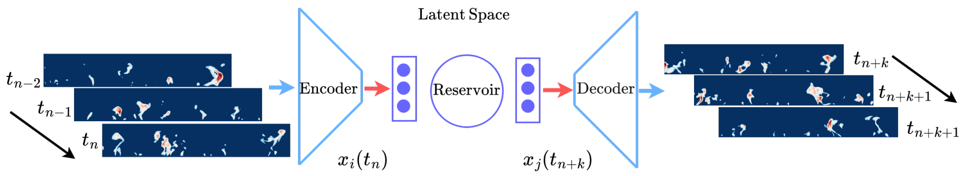

Figure 1: Inference scheme for large vertical updrafts w_p via a combined AE-RC system.

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[1]Heyder and Schumacher, *Phys. Rev. E* **103**, 053107 (2021).
[2]Heyder et al., *Phys. Rev. E* **106**, 055303 (2022).